



Landscape Transformations, Morphometry, and Trophic Status of Anchar Wetland in Kashmir Himalaya: Implications for Urban Wetland Management

Shahid Ahmad Dar · Sami Ullah Bhat ·
Irfan Rashid 

Received: 6 March 2021 / Accepted: 25 October 2021 / Published online: 3 November 2021
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2021

Abstract This study examined the current trophic state based on integrated analysis of land use land cover changes (LULCCs), morphometry, bathymetry, and water quality of a semi-urban wetland. The analysis of satellite data indicated that the wetland has lost an area of ~93 ha from 1980 to 2017. During the same period, the urban area within the wetland increased from 0.04 to 13.5%. The natural area of the wetland was lost significantly because of land conversion practices largely related to encroachments, settlements, and unplanned developmental activities. The land cover changes assessed in the immediate vicinity of wetland indicated an increase in the built-up (223%) and roads (95%). Morphometric analysis revealed that the maximum length of the wetland decreased by 775 m, while width showed an insignificant decrease. The bathymetric analysis revealed that the depth of the wetland varied from 25 to 246 cm, with a mean depth of 101.6 cm. The

Carlson's trophic state index (TSI) ranged between 71 and 80.4, indicating the hyper-eutrophic nature of the wetland. Comparison of water quality data of a wetland with the previous studies indicated a decrease of 29 cm in the maximum depth from 1980 to 2018. While NO_3^- -N increased from $300 \mu\text{g L}^{-1}$ in 1980 to $367 \mu\text{g L}^{-1}$ in 2018, total phosphorus (TP) increased from $300 \mu\text{g L}^{-1}$ in 1980 to $923 \mu\text{g L}^{-1}$ in 2018, thereby indicating continuous nutrient enrichment of the wetland. Based on the data analysis, immediate policy interventions are required to safeguard and/or reclaim this culturally and ecologically important wetland in the Kashmir region.

Keywords Land system changes · Water quality · Bathymetry · Morphometry · Anchar wetland · Kashmir Himalaya

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11270-021-05416-5>.

S. A. Dar · S. U. Bhat
Department of Environmental Science,
University of Kashmir, Hazratbal Srinagar,
Jammu and Kashmir 190006, India

I. Rashid (✉)
Department of Geoinformatics, University of Kashmir,
Hazratbal Srinagar, Jammu and Kashmir 190006, India
e-mail: irfangis@kashmiruniversity.ac.in

1 Introduction

Wetlands are areas of high biological diversity and provide many ecosystem functions of high value (Woodward & Wui, 2001; Krina et al., 2020). They have significant effects on global biotic and abiotic environmental factors and also help in the improvement of water quality (Widney et al., 2018), reduction of floods and droughts (Penatti et al., 2015); combat global climate change (Junk et al., 2013; Turner et al., 2000); protect biodiversity (MEA, 2005); and support fisheries (Keddy, 2010), agricultural food

products (MEA, 2005), and other ecosystem services and functions (Penatti et al., 2015; Reiss et al., 2014; Russi et al., 2013). Besides, the provision of research opportunities, education and nature studies, recreational amenities, and esthetics are other services provided by the wetlands (De Groot et al., 2002). However, they are also the deeply exploited systems and most threatened ecosystems of the world (Vörösmarty et al., 2010). Despite the provision of ecological services and functions by wetlands, they have been degraded (Davidson, 2014), lost (Reis et al., 2017), reclaimed (Junk et al., 2013), and strongly modified worldwide (Junk et al., 2013; Mitsch & Gosselink, 2000; Reis et al., 2017) and are under increasing stress due to agricultural intensification, pollution, encroachments, urbanization, and climate change (Torbick et al., 2006; Euliss et al., 2004; Dar et al., 2021). The increasing demand for infrastructure development is posing serious threats to the existence of wetlands (Laurance et al., 2012). The dramatic increase in the human population (Zedler & Kercher, 2005), urbanization (Bassi et al., 2014), encroachments and infrastructure development (Romshoo & Rashid, 2014), and degradation of natural landscapes (Joshi et al., 2002) greatly stressed the health of wetland ecosystems (Yu et al., 2010; Zhang et al., 2011). The quality of wetland ecosystems has been severely affected owing to an increase in anthropogenic footprint (Zedler & Kercher, 2005).

Kashmir valley in the Indian Himalayan region is known for its wetland wealth. At local levels, these are the major sources of livelihoods, moderating high pollution, and nutrient loads, trapping sediments, acting as flood absorption basins and buffers, and reducing the impact of stormwater flooding (Dar, Bhat, Rashid, & Dar, 2020b; Shah et al., 2020). These wetlands have a global significance since they support continental migratory bird diversity by providing suitable habitats for breeding and feeding during winters (Pandit, 1991). The wetland ecosystems of Kashmir regulate the regional hydrological cycle and are important sinks of carbon (Kumar, 2016). However, with the increase in the human population (Showqi et al., 2014), deforestation of catchment areas (Rashid, Bhat, & Romshoo, 2017a), and intensification of agricultural activities (Rashid & Romshoo, 2013), the wetlands of this region have been progressively degrading (Rashid & Aneaus, 2019; Romshoo & Rashid, 2014). Wetlands are being

treated as dumping grounds by both the public and policymakers as large quantities of domestic sewage, agricultural waste, plastics, and other municipal solid wastes are being directly dumped in these otherwise pristine ecosystems (Shah et al., 2015; Showqi, Lone, Mehmood, et al., 2018a).

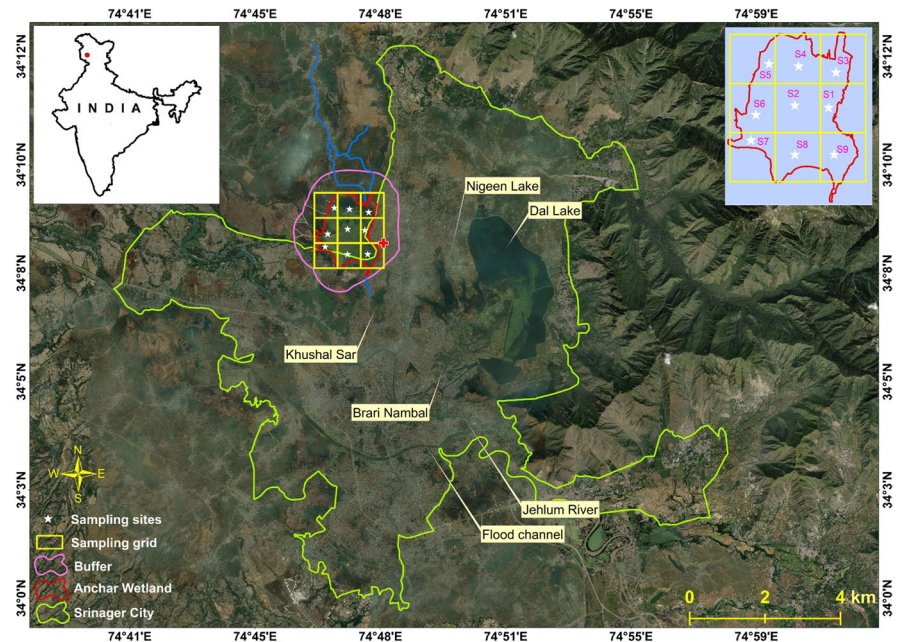
The lack of implementation of strict monitoring procedures in light of the political instability prevailing in the region over the last 3 decades has also led to the degradation of lakes and wetlands in Kashmir. Decision-makers, planners, and wetland resource managers, therefore, need reliable and updated research inputs to better understand the severity of degradation problems and devise strategies based on scientifically reliable data for the sustenance of these ecosystem reserves. In this context, monitoring LULCCs and water quality characterization can, therefore, provide valuable inputs about the ecological status of these valuable reserves for long-term sustenance. Understanding freshwater quality changes in space and time are equally paramount for precisely delineating wetland areas facing degradation and also for devising conservation strategies. Against this backdrop, we assessed the impact of land system changes on the morphometry, bathymetry, and water quality of the Anchar wetland in Kashmir Himalaya.

2 Materials and Methods

2.1 Study Area.

Anchar is a semi-urban wetland located in the Kashmir valley between geographical coordinates $34^{\circ} 20' - 34^{\circ} 36' N$ and $74^{\circ} 82' - 74^{\circ} 85' E$ at an altitude of 1583 m asl towards the northwest of Srinagar city (Fig. 1). The wetland covers an area of 690 ha. The wetland is fed by several distributaries of river Sindh on the north-western side and *Achan Nallah* on the southern side. The wetland has many outlets that drain on its western side into the Shallabugh wetland (Showqi, Lone, & Naikoo, 2018b). The wetland is important both ecologically and economically as it is a source of vegetables, fish, fodder, and wood resources. Food products harvested from the wetland such as *Nelumbo* sp. and *Trapa* sp. have high socio-economic importance. The wetland provides habitat, breeding, and nesting grounds for a large number of resident and migratory ducks, waterfowls, and other

Fig. 1 Location of the study area. Inset map: location of Anchar wetland with reference to mainland India. Background image: basemap imagery of ESRI Arc Map 10.1 of Anchar wetland and its vicinity



bird species (Fazili et al., 2017; Pandit, 1991), besides acting as a storage basin by absorbing a large volume of floodwaters during extreme floods and stormwater events.

The excessive silt load (16,707.1 metric tons of total sediment/year) brought by the Sindh river (Nisar, 2016) has not only led to the shrinkage of the area but also reduced the depth of the wetland. These problems further aggravate due to the colonization of pollution-tolerant and stress-tolerant macrophytes like *Phragmites australis*, *Sparganium ramosum*, and *Azolla* sp. Marshy lands of the wetland are continuously filled and used for agricultural production, construction of houses, and other developmental activities. The peripheries of the wetland have been taken over by willow (*Salix* sp.) plantation primarily due to their use for basket weaving and other furniture-related articles. The wetland receives large quantities

of untreated sewage and raw fecal matter from the immediate catchment on the north-eastern sides. Besides, hazardous and radioactive waste materials and toxic hospital effluents from Sher-e-Kashmir Institute of Medical Sciences are also dumped into the wetland (Hassan et al., 2020; Showqi, Lone, Mehmood, et al., 2018a).

2.2 Satellite Data Acquisition and Image Processing.

To detect LULCCs, high-resolution satellite images were used (Table 1). The wetland boundaries were delineated from satellite images using the on-screen digitization method at 1:3000 scale. To quantify the changes in the immediate catchment of Anchar wetland, a buffer of 1000 m was created around the wetland boundary in ArcMap10.1. The land use land cover (LULC) classes were delineated following

Table 1 Details of the datasets used in this study

Sensor	Acquisition date	Spatial resolution	Source
CORONA	07 October 1980	Resolution: 1.87 m	http://earthexplorer.usgs.gov/
High-resolution basemap	13 September 2017	Panchromatic: 0.46 m Multispectral: 1.65 m Accuracy: 8.47 m	ESRI basemap
GPS data	October–November 2017	Point data	Ground survey

National Natural Resources Management System (NNRMS) standards laid down by the Indian Space Research Organization (ISRO) (, 2005) and local studies (Rashid, Bhat, & Romshoo, 2017a). Reference data for validating 2017 lab-delineated land cover data was verified on the ground at 239 locations using a stratified random sampling approach (Rashid et al., 2013). The reference data for Anchar was collected during October–November, 2017 using GARMIN-Etrex Global Positioning System (GPS) with a positional accuracy of ± 5 m.

2.3 Accuracy Assessment.

Assessment of the accuracy of the LULC maps derived from remote sensing techniques is essential not only for checking the quality of the maps but also for understanding the errors and their likely implications (Foody, 2002; Hu et al., 2018). In this study, Kappa coefficient, utilizing information from the error matrix (Rashid, Bhat, & Romshoo, 2017a), and overall accuracy (Rashid et al., 2013) were generated for accuracy assessment. Kappa coefficient, a discrete multivariate technique, and a measure of accuracy (Jensen, 1996), is computed as

$$k = \frac{N \sum_{i=1}^r X_{ii} - \sum_{i=1}^r (X_{i+} \cdot X_{+i})}{N^2 - \sum_{i=1}^r (X_{i+} \cdot X_{+i})} \quad (1)$$

here k is the kappa statistic; r is the number of rows in the confusion matrix; X_{ii} is the number of observations in row i and column i ; X_{i+} is the total of observations in row i ; X_{+i} is the total of observations in column i ; and N is the total number of observations included in the matrix.

Additionally, the producer's accuracy and user's accuracy for each LULC class were computed. The producer's accuracy demonstrates the robustness of the classification algorithm/technique and indicates how well have the test set pixels of a specific land cover type been classified. It is computed by dividing the number of correctly classified pixels in each land cover type (on the major diagonal) by the number of test pixels used for that land cover type (column total). User's accuracy on the other hand indicates the probability that a pixel classified into a

given land cover type represents that land cover on the ground. It is computed by dividing the number of correctly classified pixels in each land cover type by the total number of pixels that were classified in that land cover type (row total) (Rashid et al., 2013; Lillseand et al., 2015).

2.4 Morphometry and Bathymetric Analysis.

For the morphometric characterization of the wetland, the actual wetland area comprising of open water, aquatic vegetation, and marshy lands were taken into account. A bathymetric survey was performed in spring 2018 by measuring the depth at 180 locations across the wetland. The depth was recorded using a graduated cylindrical rod of 15 m in length. The maximum depth and the mean depth were obtained using the bathymetric data. Parameters like maximum length (L_{\max}), maximum width (W_{\max}), area, and perimeter were obtained from measurements performed using high-resolution satellite imageries in ArcMap 10.1 (Table 2). The secondary parameters like relative depth and volume were calculated according to Wetzel (2001).

The bathymetric map was generated using the inverse distance weighted (IDW) algorithm (Rather & Dar, 2020; Setianto & Triandini, 2013) in ArcMap 10.1. IDW interpolation makes the supposition that the value of points that lie closer to each other are more similar than those points which are away from one another. To predict the value of an unsampled point, IDW presumes that every calculated point has a neighboring influence on the unmeasured points that diminish with distance from the measured points. The IDW algorithm is expressed as

$$Z_0 = \frac{\sum_{i=1}^n z_i \cdot d_i^{-N}}{\sum_{i=1}^n d_i^{-N}} \quad (2)$$

where Z_0 is the estimation value of variable z at point i , z_i is the sample value at point i , d_i is the distance of sample point to estimated point, N is the coefficient that determines weight based on a distance, and n is the total number of predictions for each validation case.

Table 2 Summary of the descriptive analysis of morphological parameters of Anchar wetland

S. No.	Parameter	Formula	Explanation of variables	Ecological significance
1.	Mean depth (\bar{Z})	$\bar{Z} = \frac{\sum Z}{n}$	Where Z is the value of measured depths across the lake and n is number of locations where depths were measured	<p>The depth of a lake has direct effects on its temperature, stratification, circulation, and dilution of nutrient materials. Depth also has indirect effects on the distribution and numbers of organisms. Thienemann was therefore quite justified in emphasizing mean depth as a most significant factor in determining lake type</p> <p>The general interpretation of the data presented is that morphometric factors, represented here by mean depth, are predominant in determining the fish production</p> <p>Mean depth is important because early studies of algae, aquatic invertebrates, and fish populations have shown that shallow lakes are generally more productive than deep lakes</p>
2.	Relative Depth (Z_r)	$Z_r = 50 \times Z_{\max} \times \frac{\sqrt{\pi}}{\sqrt{A_0}}$	Where Z_{\max} is the maximum depth and A_0 is the surface area	<p>The main influence of the relative depth on the functioning of the aquatic environment is related with the circulation pattern of the waterbody. Lakes that are large, but shallow, have no difficulty in circulating vertically their waters. This means that, the upper layers, which are normally rich in dissolved oxygen, can frequently reach the bottom of the lake, contributing therefore to the oxygen supply in the deep layers. The knowledge of the relative depth of the system can hence be very useful in predicting the development of eutrophication in polluted and unpolluted waters.</p> <p>The information about morphometric features of aquatic systems, especially with reference to relative depth, can effectively contribute to the important task of predicting the onset of stratification</p>
3.	Average width (b_a)	$b_a = \frac{A_0}{L}$	Where A_0 is the surface area (m^2) and L is the maximum length (m)	This measurement is also used to predict the amount of water mixing that can occur in a lake during strong winds
4.	Shoreline development (D_l)	$D_l = \frac{L}{2\sqrt{\pi A_0}}$	Where L is length of the shoreline in km and A_0 is surface area in km^2	<p>Determining a lake's shoreline development is important because it helps us assess the amount of potential wildlife habitat available for a lake. For example, if the lake has a greater amount of shoreline development, there is more of an interface between the water and surrounding land (i.e., coves and peninsulas). This interface often translates into more habitat for fish, birds and other wildlife to raise their young</p>
5.	Volume (V)	$V = A_0 \times \bar{Z}$	Where A_0 =area of lake (km^2) and \bar{Z} = mean depth	Lake volume is an important consideration to lake management, as it can influence a lake's dilution capacity
6.	Development of Volume (D_v)	$D_v = \frac{3\bar{Z}}{Z_{\max}}$	Where \bar{Z} is the mean depth and Z_{\max} is the maximum depth	

2.5 Water Quality Sampling Design.

The water quality sampling sites were selected by creating a sampling grid of 1000×1000 m in Arc-Map10.1 software (Fig. 1). To characterize surface water quality status, water samples were collected from 9 sites (Fig. 1) during four seasons—spring, summer, autumn, and winter in 2018. On spot measurements of water quality parameters including water temperature (WT), pH, electrical conductivity (EC), total dissolved solids (TDS), and salinity (Sal) were recorded using a portable multi-parameter probe (PCS Testr 35). Depth (D) was measured by a graduated rod, and Secchi Disc Transparency (SDT) was measured using Secchi disc. Other water quality parameters were assessed based on laboratory analysis following standard protocols of the American Public Health Association (APHA, 2017) (Supplementary Table 1). The average water quality data of four seasons assessed at each site was interpolated using the IDW algorithm in ArcMap 10.1.

2.6 Trophic State Index (TSI).

TSI determines the degree of productivity and nutrient enrichment of aquatic ecosystems (Xu et al., 2001). Based on the value of TSI, different aquatic ecosystems are classified into various trophic categories (Carlson, 1977; Saluja & Garg, 2017) as reflected in Supplementary Table 2. Carlson TSI of the Anchar wetland was calculated using the information of data sets of SDT, chlorophyll-a (Chl_a), and the concentration of TP.

The TSI is calculated using the equations below:

$$TSI_{SDT} = 60 - 14.41(\ln SDT) \quad (3)$$

$$TSI_{TP} = 14.42(\ln TP) + 4.15 \quad (4)$$

$$TSI_{Chla} = 9.81(\ln Chla) + 30.6 \quad (5)$$

$$TOT_{TSI} = \frac{(TSI_{SDT} + TSI_{TP} + TSI_{Chla})}{3} \quad (6)$$

where TSI_{SDT} is trophic state index corresponding to depth (m) of Secchi Disc Transparency; TSI_{TP} is trophic state index corresponding to concentration

(μgL^{-1}) of total phosphorus; TSI_{Chla} is trophic state index corresponding to phytoplankton biomass (mg m^{-3}) assessed as chlorophyll-a; and $TOT-TSI$ is total trophic state index averaged for TSI_{SDT} , TSI_{TP} , and TSI_{Chla} .

3 Results

3.1 LULCC Within the Wetland.

Analysis of satellite data of 1980 revealed that aquatic vegetation spread over 433.8 ha was the most dominant land cover type covering 62.8% of the wetland area (Fig. 2a). This was followed by open water (163.8 ha, 23.7%), marshy land (92.4 ha, 13.4%), and built-up (0.3 ha). The LULC types increased from 4 in 1980 to 7 in 2017 (Fig. 2b). Although aquatic vegetation is still a dominant land cover type covering 317.4 ha (46%), it reduced by ~27% between 1980 and 2017. The area under built-up increased by 2433% covering an area of 7.6 ha; marshy land increased by ~131% covering an area of ~214 ha in 2017. The area under open water spreading over 65.8 ha in 2017 decreased by ~60% during the observation period. The details of land system changes within the wetland are provided in Table 3. This analysis indicated that the natural land cover types within wetland have been taken over by human-induced land use types like built-up (7.6 ha), cropland (2.6 ha), open space (3 ha), and plantation (80 ha). Our analysis revealed that the area of wetland shrunk by ~13% from ~690 ha in 1980 to ~597 ha in 2017 since these areas were taken over by plantation, built-up, cropland, etc.

3.2 LULCC in the Vicinity

Major highlights of the LULCC analysis in the vicinity of the wetland from 1980 to 2017 indicate substantial shrinkage in open water (~ 59%) followed by open space (~ 37%), aquatic vegetation (~ 31%), and cropland (~ 23%). The highest increase was observed in built-up which expanded by ~224%. The area under roads increased by ~95% followed by plantation (~ 40%). The LULC maps of the Anchar vicinity for 1980 and 2017 are shown in Fig. 2c and d respectively. The detailed statistics on land system changes are provided in Table 4.

The accuracy assessment of 2017 land cover data was carried to verify the quality of information derived from satellite data. Overall, ~ 11% of digitized LULC categories were validated on the ground (Supplementary Fig. S1). The user’s accuracies for aquatic vegetation, cropland, green space, and open water were 100%, followed by roads (97%), built-up (94%), plantation (90%), and open space (73%). The producer’s accuracies (Supplementary Table 3) were 100% for aquatic vegetation and open water followed by roads (97%), plantation (94%), open space (90%), built-up (89%), and lowest for marshy land (75%). For

2017 LULC, the overall accuracy was 93% and kappa statistic 1.2. As per Lea and Curtis (2010), measurement of accuracy assessment of classified images requires the overall accuracy above 90% and kappa statistics above 0.9 which were successfully achieved in the present study.

3.3 Morphometry and Bathymetry

Morphometric analysis using satellite data revealed that the wetland had an actual surface area (excluding urban area within wetland) of 690 ha (Fig. 3a) in 1980

Fig. 2 Land use land cover within Anchar wetland **a** 1980 and **b** 2017 and in the immediate catchment of the Anchar wetland **a** 1980 and **b** 2017

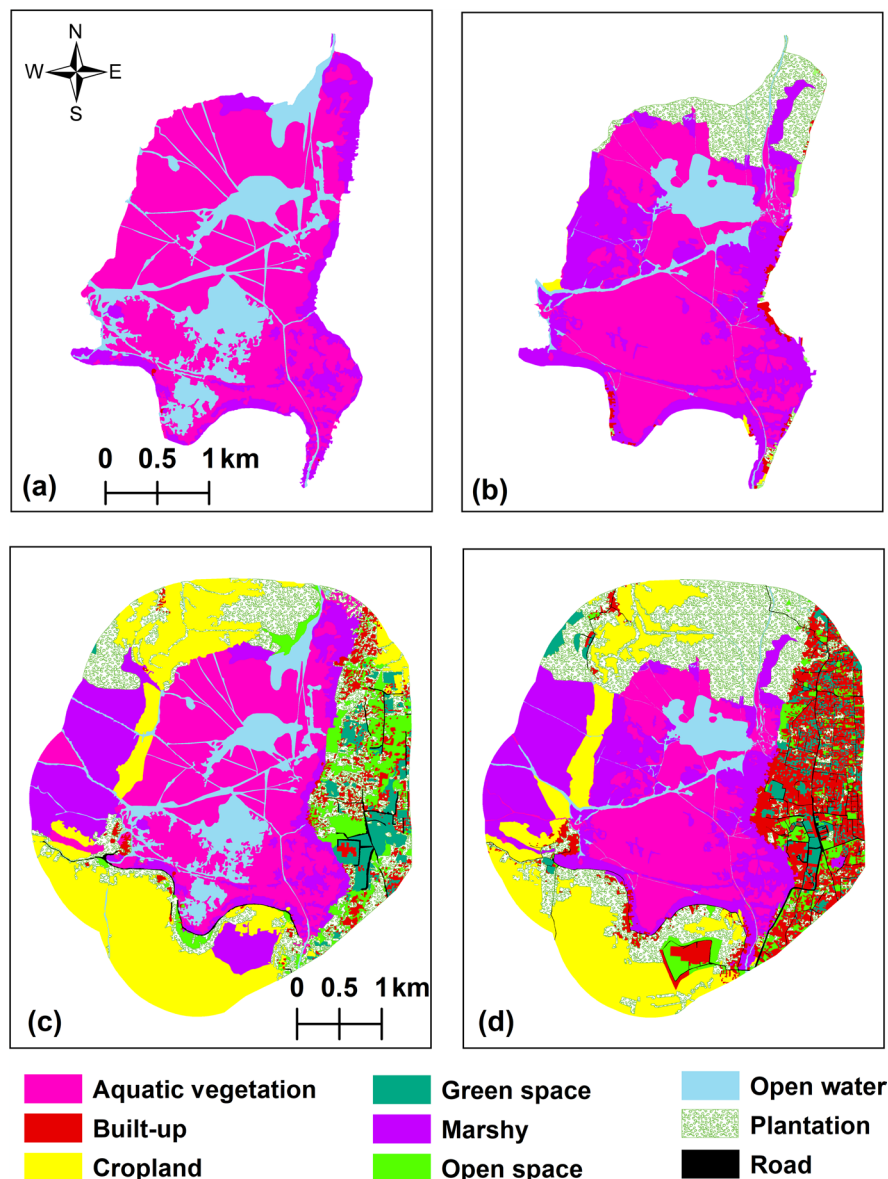


Table 3 Area under different land use land cover classes within Anchar wetland from 1980 to 2017

LULC type	Area (ha)		Change (1980–2017)	% Change (1980–2017)
	1980	2017		
Aquatic vegetation	433.8	317.4	– 116.4	– 26.8
Built-up	0.3	7.6	7.3	2433.3
Cropland	–	2.6	2.6	NA
Marshy land	92.4	213.7	121.3	131.3
Open space	–	3	3	NA
Open water	163.8	65.8	– 98	– 59.8
Plantation	–	80.2	80.2	NA
Total area	690.3	690.3		

which reduced to ~597 ha in 2017 (Fig. 3b). Details of various morphometric features are provided in Table 5. The maximum length of the wetland reduced from 4701 m in 1980 (Fig. 3c) to 3926 m in 2017 (Fig. 3d). The maximum width changed from 3272 m in 1980 (Fig. 3e) to 3261 m in 2017 (Fig. 3f) indicating an insignificant decrease. The depth data collected at 180 locations were interpolated using IDW to produce a bathymetry map as shown in Fig. 4. The bathymetric analysis revealed that the depth of the wetland varies from 25 to 246 cm, while the mean depth is 102 cm.

3.4 Water Quality

The water quality characteristics of the wetland examined at 9 sites revealed significant spatio-temporal variations. The WT of the wetland followed a seasonal trend being maximum in summer (25 °C) and minimum in winter (8 °C). The water of the wetland is neutral to slightly alkaline with a pH value ranging from 7 to 8.8. EC ranged from 295 $\mu\text{S cm}^{-1}$ at site 6 to 634 $\mu\text{S cm}^{-1}$ in summer at site 1. TDS ranged from 210 mg L^{-1} at site 6 during summer to a maximum of 413 ppm at site 7 during winter. Salinity ranged from 138 mg L^{-1} at site 6 during summer to 249 mg L^{-1} at site 8 during winter. The transparency showed a seasonal pattern of being maximum in winter followed by spring, autumn, and summer. SDT ranged from 27 cm at site 1 during spring to 127 cm at site 4 during summer. Depth ranged from 51 cm at site 1 during spring to a maximum of 246 cm at site 4 during spring. DO ranged from 0.8 mg L^{-1} at site 1 and 7 to

Table 4 Area under different land use land cover classes in immediate vicinity of Anchar from 1980 to 2017

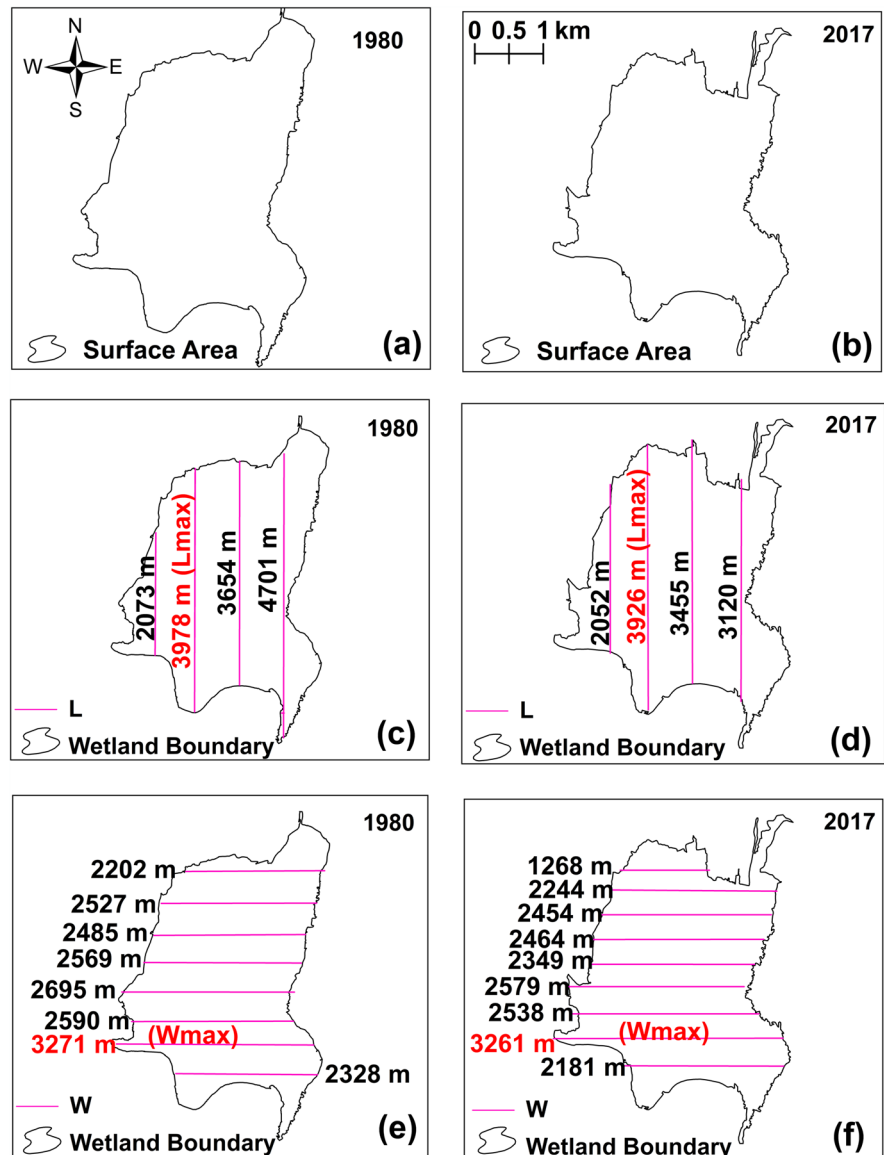
LULC type	Area (ha)		Change (1980–2017)	% Change (1980–2017)
	1980	2017		
Aquatic vegetation	460.2	319.5	– 140.7	– 30.6
Built-up	69	223	154	223.2
Cropland	390.1	301.5	– 88.6	– 22.7
Green space	57.8	67.6	9.8	16.9
Marshy land	282.9	369.2	86.3	30.5
Open space	95.9	60.7	– 35.2	– 36.7
Open water	174.2	70.6	– 103.6	– 59.5
Plantation	255.9	358.4	102.5	40
Road	16.3	31.8	15.5	95
Total area	1802.3	1802.3		

a maximum of 4.8 mg L^{-1} at site 4 during spring. The interpolated mean values of WT, pH, EC, TDS, Sal, SDT, D, and DO are shown in Fig. 5.

Total alkalinity (TA) ranged from 98 mg L^{-1} at site 6 during summer to 268 mg L^{-1} at site 1 during autumn. Free carbon dioxide (F-CO₂) concentration recorded in the wetland ranged between 4.7 mg L^{-1} during summer and 23 mg L^{-1} at site 4 during autumn. The T-hard values ranging from 140 mg L^{-1} in summer to 240 mg L^{-1} in winter indicate that the waters of the wetland are hard to very hard water type. TA (HCO_3^- , CO_3^{2-}) was highest followed by calcium (Ca). The order of equivalency of cations and anions is (HCO_3^- , CO_3^{2-}) > Ca^{2+} > Mg^{2+} > Cl^- . The interpolated mean values of TA, F-CO₂, T hard, Ca hard, Mg hard, Ca, Mg, and Cl are shown in Fig. 6.

Ammoniacal nitrogen (NH₃-N) ranged from a minimum of 274 $\mu\text{g L}^{-1}$ at site 6 in winter to a maximum of 985 $\mu\text{g L}^{-1}$ at site 1 and 3 during autumn. Nitrite nitrogen (NO₂⁻-N) ranged from 11 $\mu\text{g L}^{-1}$ at site 4 during summer to 68 $\mu\text{g L}^{-1}$ at site 1 during winter. Nitrate nitrogen (NO₃⁻-N) concentration ranged from 170 $\mu\text{g L}^{-1}$ at site 4 during winter to a maximum of 735 $\mu\text{g L}^{-1}$ at site 9 in winter. Total Kjeldahl nitrogen (TKN) ranged from 1.1 mg L^{-1} to a maximum of 2.8 mg L^{-1} during autumn. Total nitrogen (TN) ranged from a minimum of 1.4 mg L^{-1} in winter to a maximum of 3.6 mg L^{-1} at site 1 during autumn. Orthophosphorus (Ortho-P) ranged from a minimum of 145 $\mu\text{g L}^{-1}$ at site 2 during spring to a maximum of 656 $\mu\text{g L}^{-1}$ at site 9 during winter. TP ranged from

Fig. 3 Morphometric features of Anchar wetland: **a** surface area (ha) 1980, **b** surface area (ha) 2017, **c** length (m) 1980, **d** length (m) 2017, **e** width (m) 1980, and **f** width (m) 2017



a minimum of $518 \mu\text{g L}^{-1}$ at site 5 during spring to a maximum of $1428 \mu\text{g L}^{-1}$ at site 8 during winter. Chl_a ranged from a minimum of 7.4 mg m^{-3} during winter to a maximum of 49.5 mg m^{-3} at site 4 during summer. The interpolated mean values of $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, TKN, TN, Ortho-P, TP, and Chl_a are shown in Fig. 7.

3.5 TSI

The TSI_{SDT} ranges from 56.5 at site 4 during summer to 78.9 at site 1 during spring (Fig. S2a,b,c,d). The

mean TSI_{SDT} values of the four seasons range from 60 to 71.7 (Fig. S2e) indicating the eutrophic to hyper-eutrophic nature of the wetland. The seasonal variation in the TSI_{TP} values is shown in Fig. S3 a, b, c, and d. The mean values of TSI_{TP} shown in Fig. S3e indicate that the wetland falls in the hyper-eutrophic category. The seasonal variation of TSI_{Chla} is shown in Fig. S4 a, b, c, and d. The mean concentration of TSI_{Chla} indicates that the wetland remains in a eutrophic state (Fig. S4e). The seasonal variation of TOT_{TSI} values shown in Fig. 8a, b, c, and d indicates that the wetland remains hyper-eutrophic during all

Table 5 Morphometric features of Anchar wetland

S. No.	Morphometric parameters	1980	2018
1.	Surface area (ha)	690	597
2.	Maximum length (m)	4701	3926
3.	Maximum width (m)	3272	3261
4.	Average width (m)	1467.8	1510.2
5.	Maximum depth (cm)	300	246
6.	Mean depth (cm)	–	101.6
7.	Relative depth (%)	–	0.09
8.	Volume (m. m ³)	–	6,065,520
9.	Perimeter (km)	16.1	15.5
10.	Shoreline development	0.66	0.74
11.	Volume development	–	1.23

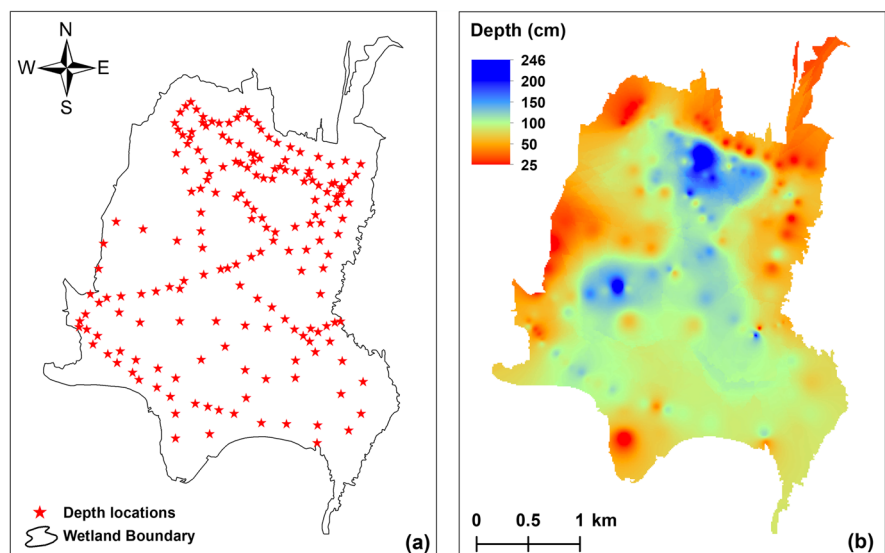
four seasons of the year. Overall, the mean interpolated TOT_{TSI} values ranging from 73 to 78 (Fig. 8e) are indicative of the hyper-eutrophic nature of the wetland.

4 Discussion

Between 1980 and 2017, a substantial area of wetland (93 ha, 13.5%) has been lost owing to land system transformations both within and in the vicinity of Anchar wetland. The decrease in the wetland extent is mainly related to encroachments and conversion of wetland areas into built-up, cropland, and plantations.

Similar observations have been reported by Rashid and Aneaus (2019) and Dar et al. (2021) for other urban and semi-urban wetlands of Kashmir. The aquatic vegetation decreased by ~116 ha and open water by 98 ha. The decrease in the spread of aquatic vegetation is attributed to the ongoing nutrient enrichment (Bakker et al., 2013; Gulati & van Donk, 2002) of the wetland. The shallow areas along the periphery of the wetland are continuously landfilled. These land-filled areas result in open spaces which after some time are used for raising croplands and finally for the construction of houses. An increase in marshy areas and land-filled areas has been reported for other wetlands in the Kashmir region (Bhat et al., 2019; Dar, Bhat, Rashid, & Dar, 2020b; Pandit, 1988). The wetland is nowadays used as a wasteland given the fact that a huge quantity of municipal solid wastes, agricultural waste, domestic sewage, and even hazardous hospital wastes are dumped in the wetland from the neighboring settlement areas without any prior treatment (Showqi, Lone, & Naikoo, 2018b). Similar pressures are being faced by other urban, semi-urban, and rural wetlands across Kashmir Himalaya (Najar et al., 2017; Shah et al., 2015); however, the dumping of hazardous hospital wastes is unique to Anchar wetland (Mir et al., 2005). The hazardous wastes and heavy metals have a high affinity for bioaccumulation in edible aquatic macrophytes of the wetland. The elevated levels of heavy metals at different sites of the Anchar wetland reported by

Fig. 4 a Depth measurements of Anchar wetland. b Bathymetry map of Anchar wetland



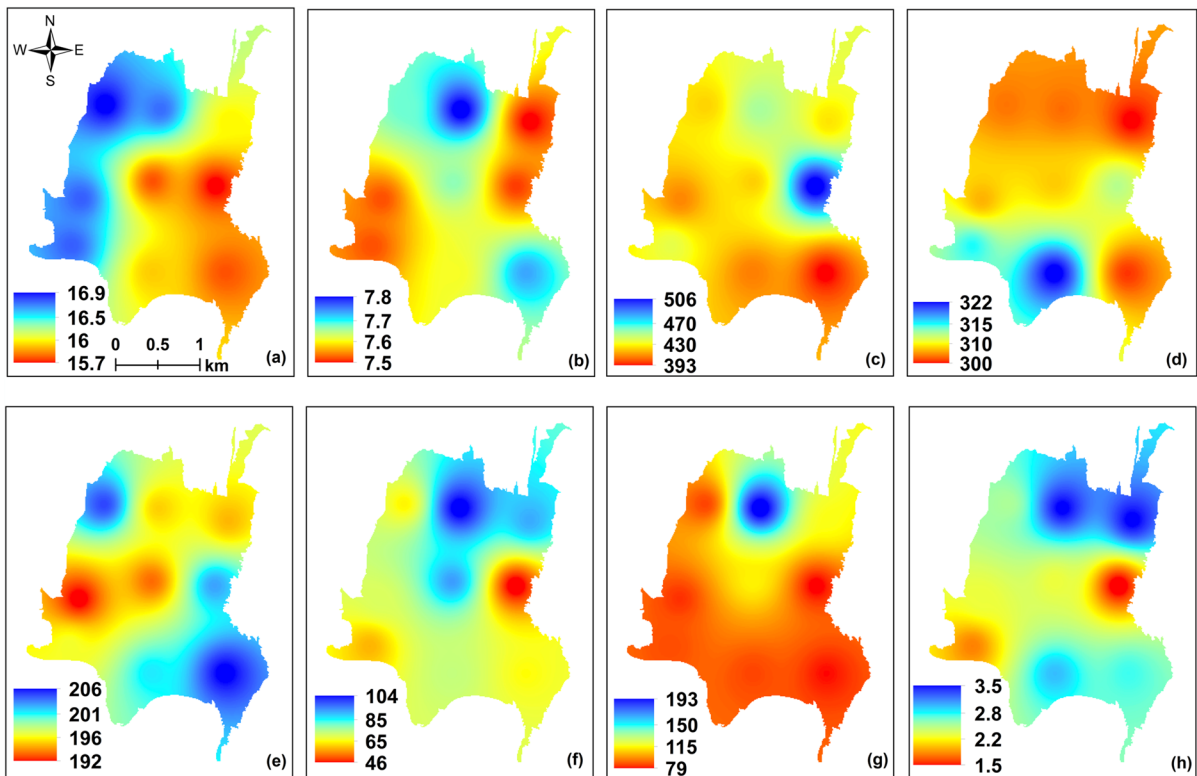


Fig. 5 Mean spatial variations in **a** WT ($^{\circ}\text{C}$), **b** pH, **c** EC ($\mu\text{S cm}^{-1}$), **d** TDS (mg L^{-1}), **e** Sal (mg L^{-1}), **f** SDT (cm), **g** D (cm), and **h** DO (mg L^{-1})

Showqi, Lone, and Naikoo (2018b) are of utmost concern because of the biomagnification process through the food chain. Due to siltation and soil erosion from the catchment (Alam et al., 2011; Badar et al., 2013; Romshoo et al., 2017) and decrease in-stream flows (Rashid et al., 2020; Romshoo & Rashid, 2014; Showqi et al., 2014), the depth of wetland decreased. This has altered the wetland hydrology and resulted in the expansion of marshy areas that over time have been transformed either into open spaces for the construction of settlements or plantations. The enormous anthropogenic pressures have translated into wetland loss since the neighboring settlements areas proliferated and expanded into the wetland. Although the Government has established several conservation agencies like Department of Wildlife Protection Jammu & Kashmir, Lakes and Waterways Development Authority (LAWDA), various Developmental Authorities, like Manasbal Development Authority (MDA), Wular Development Authority, Wular Conservation and Management Authority (WUCMA),

etc. for management of lakes and wetlands in Kashmir region, these managing bodies have failed in the ensuring protection of important wetland reserves. The wetland is continuously overlooked in any conservation and management plans and has been abandoned by the conservation agencies.

The wetland vicinity also faced a brunt of land transformations between 1980 and 2017. The area under settlements, roads, and green spaces increased by 224%, 95%, and 17% respectively. Similar findings have been reported by Rather et al. (2016) for the Kashmir region; however, the massive land system changes associated with depleting stream flows and urbanization have turned Anchar lake hyper-eutrophic. The exacerbated population growth and urbanization appear to be the prime drivers of encroachments, environmental degradation, and wetland change. The area under plantation has increased as the northern periphery of the wetland is surrounded by a thick canopy of willow (*Salix* sp.) and poplar (*Populus* sp.) trees, in which the wood is used

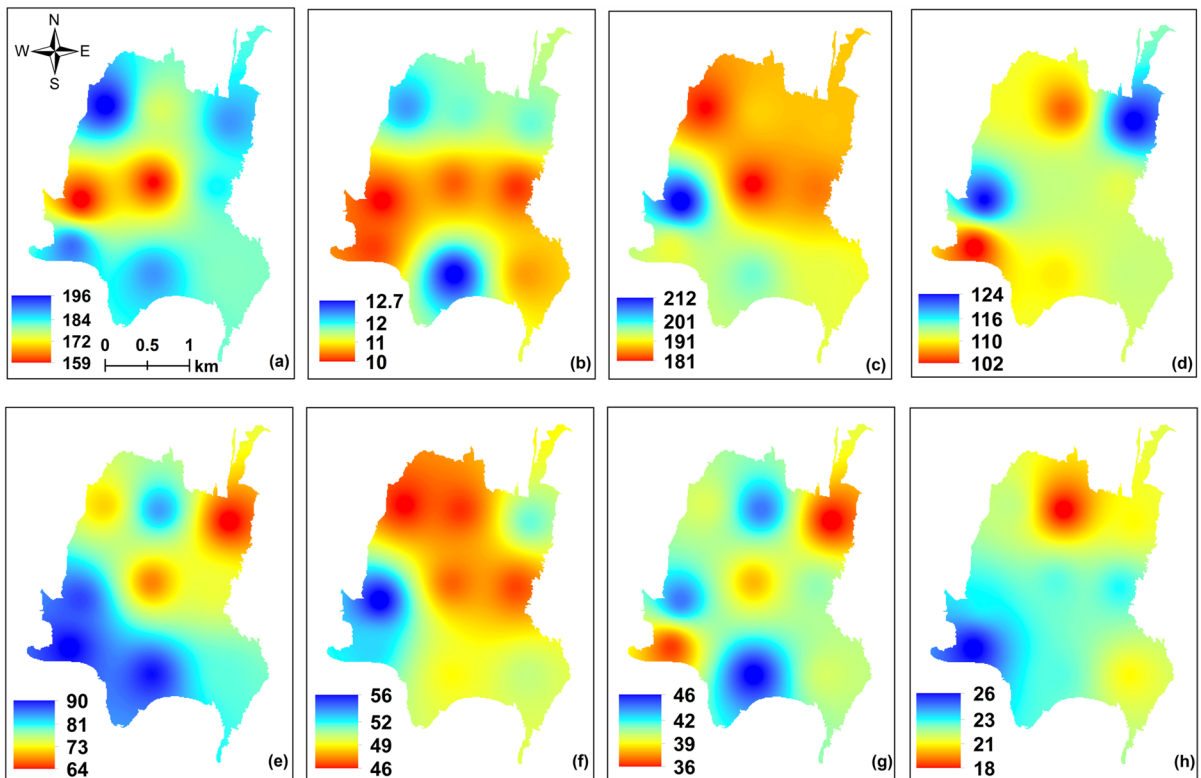


Fig. 6 Mean spatial variations in **a** TA (mg L^{-1}), **b** F- CO_2 (mg L^{-1}), **c** T-hard (mg L^{-1}), **d** Ca hard (mg L^{-1}), **e** Mg hard (mg L^{-1}), **f** Ca (mg L^{-1}), **g** Mg (mg L^{-1}), and **h** Cl (mg L^{-1})

for making furniture, baskets, cricket bats, and other wicker articles (Jeelani & Kaur, 2012; Shah et al., 2020). The area under cropland and open space shrunk during the 37 years of the observation period. This decrease is attributed to the rapid expansion of settlements in the area that have taken over these LULC types.

With the unceasing expansion of settlements, most of the wetland area and agricultural fields have been taken over by settlements. Additionally, the discharge of untreated fecal matter, domestic sewage, and the effluents from stables of livestock has led to acute water pollution not only destroying the esthetic beauty of the wetland but also its hydrobiological setup. The encroachments and unplanned development around the wetland have not only caused deterioration of chemical quality of water but also turned the wetlands peripheries into easily amenable solid waste dumping sites. It is pertinent to mention that while built-up is the predominant land use type occupying $\sim 12.4\%$ of the immediate catchment of Anchar,

there is no sewage treatment plant for decontaminating the domestic sewage that pours through open drains directly into the wetland.

Anchar is a drainage/flow-through system type of wetland with both inlet and outlet. The water supply is highly regulated and maintained by inflows from river Sindh and *Achan Nallah* from Khushalsar wetland which is fed by Dal Lake. The wetland has a small surface area which highlights the little effects of wind on the water column and the least dilution capacity of the wetland. During the last 4 decades, the shoreline is highly modified by human activities due to encroachments and landfilling. Since the ratio of shoreline development is related to a circle, a perfectly round basin would have an index of 1.0. Therefore, the value of shoreline development approaching 1 indicates that the wetland is becoming circular and reflects the potential for the development of littoral communities (plants) and high biological productivity. Zutshi et al. (1980) reported a maximum depth of 275 cm in Anchar which at present study reduced

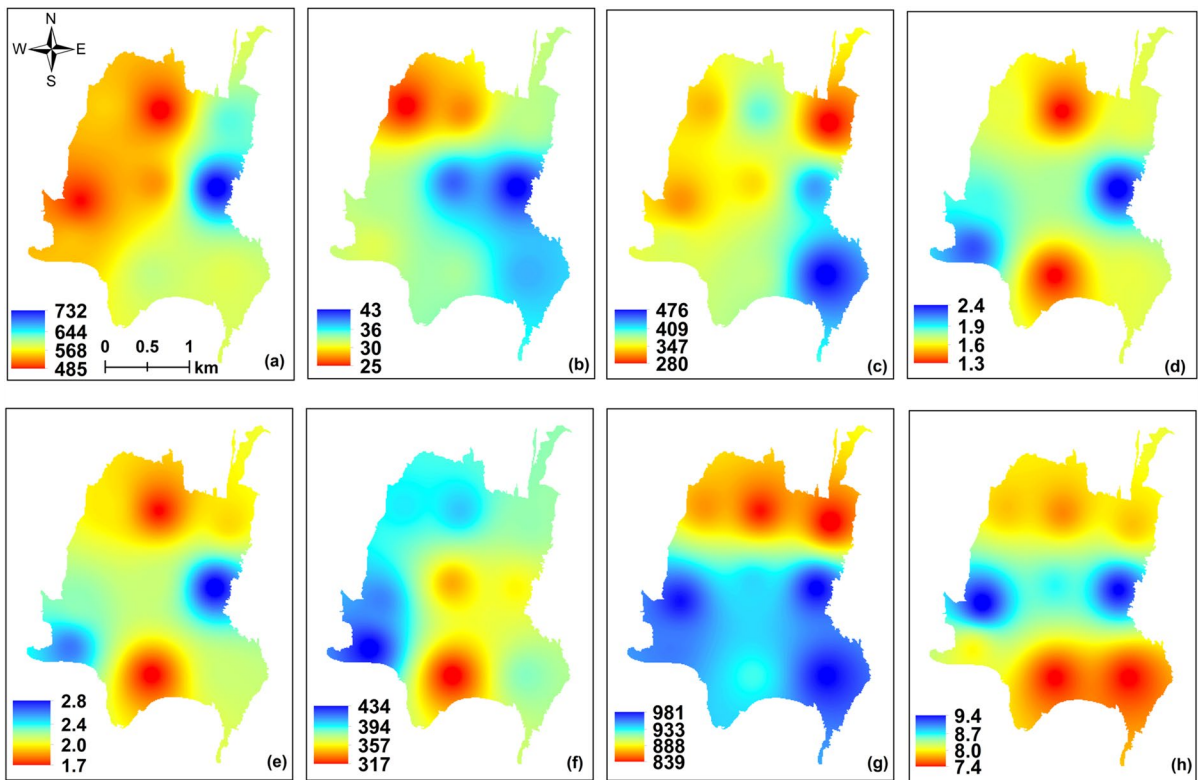


Fig. 7 Mean spatial variations in **a** $\text{NH}_3\text{-N}$ ($\mu\text{g L}^{-1}$), **b** $\text{NO}_2\text{-N}$ ($\mu\text{g L}^{-1}$), **c** $\text{NO}_3\text{-N}$ ($\mu\text{g L}^{-1}$), **d** TKN (mg L^{-1}), **e** TN (mg L^{-1}), **f** Ortho-P ($\mu\text{g L}^{-1}$), **g** TP ($\mu\text{g L}^{-1}$), and **h** Chl_a (mg m^{-3})

to only 246 cm. This loss of 29 cm of the water column from 1980 to 2018 is related to the large quantities of silt and sediments brought by river Sindh on the north-western side of the wetland (Gulzar & Abubakr, 2019). The deposition of silt and sediments in the wetland resulted in vast alluvial plains supporting large marshlands. As a result, the wetland is heavily impacted by dense macrophytes like *Azolla* sp., *Phragmites* sp., *Typha* sp., *Menyanthes* sp., *Cyperus* sp., *Carex* sp., *Ranunculus* sp., *Sparganium ramosum*, and *Scirpus* sp. (Ali & Pandit, 2009). The wetland is shallow with a mean depth of 101.6 ± 43.2 cm. The volume of the wetland reflects the potential for dilution and also the storage capacity of the water during floods and stormwater events.

The WT of the wetland is related to the temperate climate/ambient air temperature of the Kashmir valley, with higher temperatures in the summer season and lower temperatures in the winter season (Dar, Bhat, Aneaus, & Rashid, 2020a; Shah et al., 2017). The slightly alkaline nature of the water of

the wetland is attributed to the presence of calcium-rich rocks in catchments of Kashmir wetlands and lakes (Zutshi et al., 1980). Modest seasonal fluctuations in pH are attributed to the buffering capacity of water (Boven et al., 2008). The high values of EC, TDS, and salinity are attributed to the addition of ions, silt load, and sewage inflows from residential areas and discharge of pollutants from the immediate catchment having a high concentration of ions (Badar et al., 2013; Parvez & Bhat, 2014). SDT was generally low over sites because of the absorption of light by a heavy load of particulate, dissolved organic matter, and phytoplankton blooms (Harvey et al., 2019; Khanday et al., 2018; Nissa & Bhat, 2016). The transparency values were compared with the trophic classification scheme proposed by Organization for Economic Cooperation and Development (OECD, 1982), and it was found that the wetland falls in the hyper-eutrophic category. Due to siltation and soil erosion from the catchment, the maximum depth of 275 cm during the 1980s (Zutshi et al., 1980) decreased to

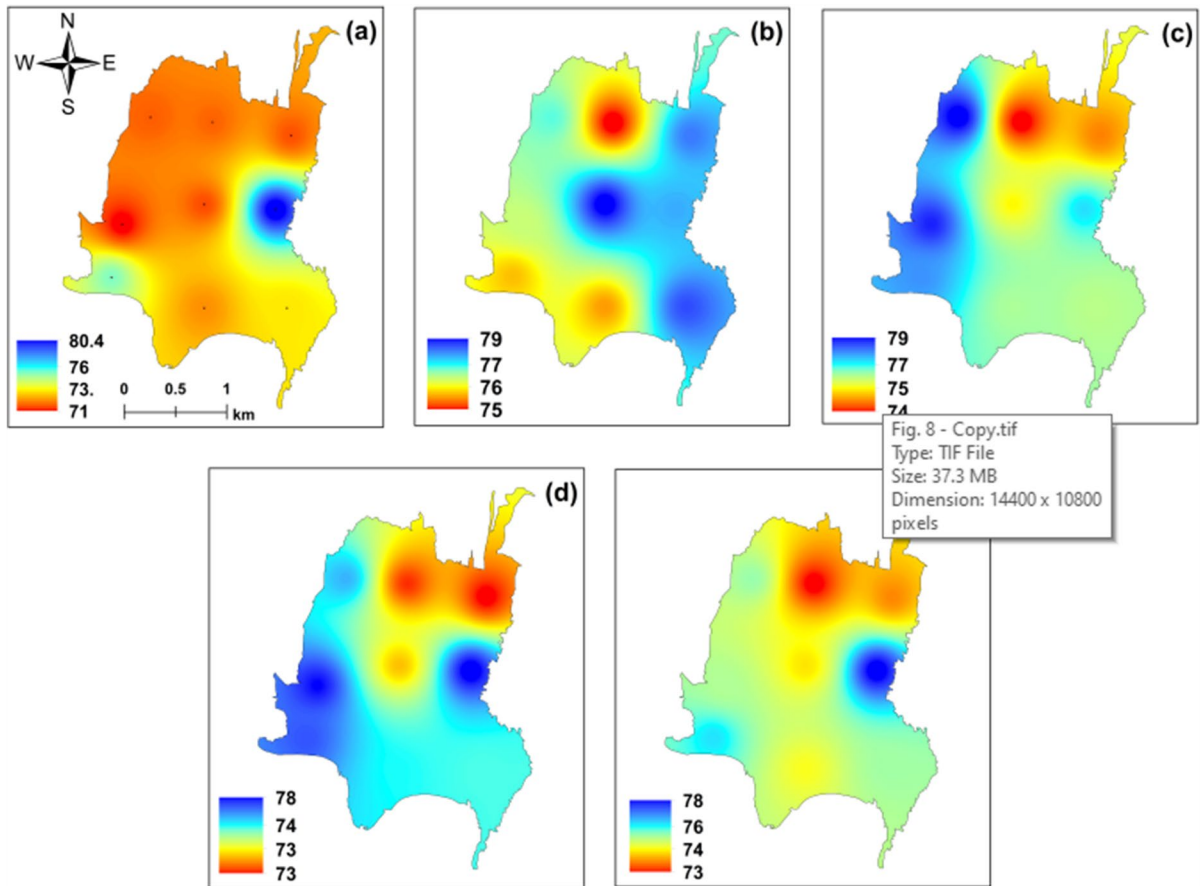


Fig. 8 Spatial variations in TOT_{TSI} : **a** spring, **b** summer, **c** autumn, **d** winter, and mean annual variations

246 cm at present. The low depth value across all sites is ascribed to depleting stream flows (Romshoo et al., 2015), the buildup of organic matter (Khanday et al., 2018), and sediment load from the Sindh river. The relatively lower concentration of DO despite rich macro-vegetation can be related to the hyper-eutrophic condition of the wetland which is the result of high rates of decay of organic material throughout the year (Dar et al., 2012; Siraj et al., 2010). The high Cl content in the wetland indicates the presence of organic matter, pollution, and flow of sewage (Bhat & Pandit, 2014; Rather et al., 2016). Among various nitrogen species, NH_3-N was found to be the dominant form in the wetland and is related to sewage ingress from adjoining settlements (Parvez & Bhat, 2014). TN content in the wetland is related to fertilizer inputs from agricultural fields, direct disposal of domestic, and defecation wastes of both human and

animal origin into wetland (Showqi, Lone, & Naikoo, 2018b; Sushil et al., 2014). The TP concentration in the wetland is related to the high effluent load of phosphorus from surface runoff, animal wastes, and domestic sewage to the wetland (Bhat et al., 2013), which indicates the hyper-eutrophic nature of the wetland (OECD, 1982). Chl_a concentration in the wetland is related to the abundance of phytoplankton, high concentration of TP, and algal blooms in the wetland (Banita et al., 2013; Filstrup & Downing, 2017; Malik et al., 2017).

The analysis of water quality data sets revealed that there has been a progressive increase in the concentration of various parameters like NO_3^-N , Ortho-P, and TP than the earlier records of Zutshi et al. (1980). NO_3^-N increased from $300 \mu g L^{-1}$ in 1980 to $367 \mu g L^{-1}$ in 2018, Ortho-P increased from $6 \mu g L^{-1}$ in 1980 to $405 \mu g L^{-1}$ in 2018, and TP increased

from $300 \mu\text{g L}^{-1}$ in 1980 to $923 \mu\text{g L}^{-1}$ in 2018. This increase in the water quality parameters is attributed to the increase in the built-up area around the wetland and subsequent discharge of sewage and organic pollutants to the wetland (Haidary et al., 2013; Rashid, Romshoo, et al., 2017b). The wetland receives a waste load of 82.39 t/year of nitrogen and 5.73 t/year of phosphorus (Tahseen et al., 2018). The annual mean of the water quality parameters has increased in the wetland. This is related to the filth resulting from the transformation of open spaces into built-up areas, storm-water runoff from urban areas and to direct ingress of sewage and fecal matter, nutrient, and sediment loadings to the wetland (Badar et al., 2013; Rashid et al., 2013; Romshoo et al., 2011; Romshoo & Muslim, 2011).

The eutrophic to hyper-eutrophic state based on TSI_{SDT} values is attributed to the luxuriant growth of macrophytes, the dominance of algal populations besides the turbid waters brought by river Sindh (Tahseen et al., 2018). The hyper-eutrophic state based on TSI_{TP} is related to the high phosphorus inputs from detergents animal dung wastes and the release of phosphorus from sediments during dewatering and *Nadru* rhizome harvesting. The eutrophic state based on TSI_{Chl} is related to the abundance of phytoplankton populations in the wetland (Khanday & Khanday, 2018). Based on TOT_{TSI} values, the present hyper-eutrophic state can lead to the vanishing of the wetland given the proliferation of macrophytes, expansion of marshlands, and ingress of solid wastes including animal wastes into the wetland.

5 Conclusions

From the study, it is concluded that human activities, encroachments, and settlements are the major causes responsible for the reduction of the extent of the Anchar wetland. The discharge of untreated domestic sewage and raw fecal matter from the nearby habitations is responsible for the cultural hyper-eutrophication of the wetland. The dumping of plastics and municipal solid wastes by locals is a major threat to the ecology of the wetland. Lack of adequate sewage treatment facilities and the absence of conservation and management bodies are the major factors responsible for the pathetic condition of the wetland. To protect the health of the wetland from further

deterioration, it is therefore essential to put some conservation and restoration measures for reviving the glory and health of the wetland. Therefore, some measures are crucial to be adopted as follows:

- (1) The construction of sediment settling basins at the northern inlet of the wetland to trap sediments brought by River Sindh. The Rakhi Kujar wetland on the north of Anchar wetland could act as a possible bio-filter for trapping the sediments brought by river Sindh.
- (2) Implementation of a complete blanket ban on all construction activity up to some specified distance from the wetland along with detailed land use planning would be beneficial to control further deterioration of the wetland.
- (3) Construction of robust sewage treatment plants at Anchar and Buchpora locality to treat the raw fecal matter and domestic sewage before being discharged to the wetland.
- (4) Delimitation and fencing of the natural area of the wetland to prevent the dumping of solid wastes and encroachments by the local inhabitants.
- (5) Setting up a separate authority under the charge of a senior functionary and entrust all work relating to the development of the wetland and its periphery to this authority.

Author Contribution Shahid Ahmad Dar: Methodology, Data analysis, Software, Writing-original draft preparation. Sami Ullah Bhat: Conceptualization, Supervision, Writing-reviewing and editing. Irfan Rashid: Conceptualization, Methodology, Supervision, Writing-reviewing and editing.

Funding The first author has received financial support from University Grants Commission-Maulana Azad National Fellowship under grant number 201819-MANF-2018-19-JAM-90477 for carrying out the study.

Data Availability The datasets generated during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics Approval and Consent to Participate Research ethics stand adhered to while submitting the manuscript.

Consent for Publication

All the authors approved the manuscript to be published.

Conflict of Interest The authors declare no competing interests.

References

- Alam, A., Rashid, S. M., Bhat, M. S., & Sheikh, A. H. (2011). Impact of land use/land cover dynamics on Himalayan wetland ecosystem. *Journal of experimental sciences*, 2, 60–64. Weblink: <https://updatepublishing.com/journal/index.php/jes/article/view/1819>
- Ali, N., & Pandit, A. K. (2009). Macrophytic diversity in Anchar lake, Kashmir. *Journal of Research and Development*, 9, 13–19.
- American Public Health Association (APHA). (2017). *Standard methods for the examination of water and waste water* (23rd ed.). Washington.
- Badar, B., Romshoo, S. A., & Khan, M. A. (2013). Modeling the catchment hydrological response in a Himalayan lake as a function of changing land system. *Earth System Science*, 112, 433–449. <https://doi.org/10.1007/s12040-013-0285-z>
- Bakker, E. S., Sarneel, J. M., Gulati, R. D., Liu, Z., & van Donk, E. (2013). Restoring macrophyte diversity in shallow temperate lakes: Biotic versus abiotic constraints. *Hydrobiologia*, 710, 23–37. <https://doi.org/10.1007/s10750-012-1142-9>
- Banita, D. M., Tapati, D., & Susmita, G. (2013). Limnological studies of temple ponds in Cachar District, Assam, north East India. *International research journal of environment sciences*, 2, 49–57. Weblink: http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue52/bibliography/limnological-studies-of-temple-ponds-in-cachar-district-assam.pdf
- Bassi, N., Kumar, M. D., Sharma, A., & Pardha-Saradhi, P. (2014). Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies. *Journal of Hydrology: Regional Studies*, 2, 1–19. <https://doi.org/10.1016/j.ejrh.2014.07.001>
- Bhat, M. S., Ahmad, B., Alam, A., Farooq, H., & Ahmad, S. (2019). Flood hazard assessment of the Kashmir Valley using historical hydrology. *Journal of Flood Risk Management*, 12, 1–13. <https://doi.org/10.1111/jfr3.12521>
- Bhat, S. A., & Pandit, A. K. (2014). Surface water quality Assessment of Wular Lake, a Ramsar site in Kashmir Himalaya, using discriminant analysis and WQI. *Journal of Ecosystems*, 724728, 1–18. <https://doi.org/10.1155/2014/724728>
- Bhat, S. A., Meraj, G., Yaseen, S., Bhat, A. B., & Pandit, A. K. (2013). Assessing the impact of anthropogenic activities on spatio-temporal variation of water quality in Anchar lake, Kashmir Himalayas. *International Journal of Environmental Sciences*, 3, 1625–1640. <https://doi.org/10.6088/ijes.2013030500032>
- Boven, L., Stoks, R., Forró, L., & Brendonck, L. (2008). Seasonal dynamics in water quality and vegetation cover in temporary pools with variable hydroperiods in Kiskunság (Hungary). *Wetlands*, 28, 401–410. <https://doi.org/10.1672/06-174.1>
- Carlson, R. E. (1977). A trophic state index for lakes. *American Society of Limnology and Oceanography*, 22, 361–369. <https://doi.org/10.4319/lo.1977.22.2.0361>
- Dar, N. A., Hamid, A., Ganai, B. A., Bhat, S. U., & Pandit, A. K. (2012). Primary production dynamics of two dominant macrophytes in Wular Lake, a Ramsar site in Kashmir Himalaya. *Ecologia Balkanica*, 4, 77–83. Weblink: <http://www.oalib.com/paper/2037781#.XxB6uCgzBIU>
- Dar, S. A., Rashid, I., & Bhat, S. U. (2021). Land system transformations govern the trophic status of an urban wetland ecosystem: Perspectives from remote sensing and water quality analysis. *Land Degradation & Development*, <https://doi.org/10.22541/au.160071436.64933166>
- Dar, S. A., Bhat, S. U., Aneaus, S., & Rashid, I. (2020a). A geospatial approach for limnological characterization of Nigeen Lake, Kashmir Himalaya. *Environmental Monitoring and Assessment*, 192, 1–18. <https://doi.org/10.1007/s10661-020-8091-y>
- Dar, S. A., Bhat, S. U., Rashid, I., & Dar, S. A. (2020b). Current status of wetlands in Srinagar City: Threats, management strategies, and future perspectives. *Frontiers in Environmental Science*, 7, 1–11. <https://doi.org/10.3389/fenvs.2019.00199>
- Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Mar Freshwater Res*, 65, 934–941. <https://doi.org/10.1071/MF14173>
- De Groot, R. S., Wilson, M. A., & Boumans, R. M. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41, 393–408. [https://doi.org/10.1016/S0921-8009\(02\)00089-7](https://doi.org/10.1016/S0921-8009(02)00089-7)
- Euliss, N., LaBaugh, J., Fredrickson, L., Mushet, D., Laubhan, M., Swanson, G., Winter, T., Rosenberry, D., & Nelson, R. (2004). The wetland continuum: A conceptual framework for interpreting biological studies. *Wetlands*, 24, 448–458. [https://doi.org/10.1672/0277-5212\(2004\)024\[0448:TWCACF\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2004)024[0448:TWCACF]2.0.CO;2)
- Fazili, M. F., Bhat, B. A., Ahangar, F. A. (2017). Avian diversity of Anchar lake, Kashmir, India. *New York science journal*, 10, 92–97. Weblink: http://www.sciencepub.net/newyork/ny100117/15_31593nys100117_92_97.pdf
- Filstrup, C. T., & Downing, J. A. (2017). Relationship of chlorophyll to phosphorus and nitrogen in nutrient-rich lakes. *Inland Waters*, 7, 385–400. <https://doi.org/10.1080/20442041.2017.1375176>
- Foody, G. M. (2002). Status of land cover classification accuracy assessment. *Remote Sensing of Environment*, 80, 185–201. [https://doi.org/10.1016/S0034-4257\(01\)00295-4](https://doi.org/10.1016/S0034-4257(01)00295-4)
- Gulati, R. D., & van Donk, E. (2002). Lakes in the Netherlands, their origin, eutrophication and restoration: State-of-the-art review. *Hydrobiologia*, 478, 73–106. <https://doi.org/10.1023/A:1021092427559>
- Gulzar, B., & Abubakr, A. (2019). Present trophic status of Anchar Lake, Kashmir: Assessment by water quality parameters. *Journal of Pharmacognosy and Phytochemistry*, 8, 2018–2023. Weblink: <http://www.phytojournal.com/archives/2019/vol8issue4/PartAH/8-4-372-388.pdf>

- Haidary, A., Amiri, B. J., Adamowski, J., Fohrer, N., & Nakane, K. (2013). Assessing the impacts of four land use types on the water quality of wetlands in Japan. *Water Resources Management*, 27, 2217–2229. <https://doi.org/10.1007/s11269-013-0284-5>
- Harvey, E. T., Walve, J., Andersson, A., Karlson, B., & Kratzer, S. (2019). The effect of optical properties on Secchi depth and implications for eutrophication management. *Frontiers in Marine Science*, 5, 496. <https://doi.org/10.3389/fmars.2018.00496>
- Hassan, B., Ali, M.-N., & Qadri, H. (2020). Cytotoxic and genotoxic assessment of sewage treatment plant at Sher-I-Kashmir Institute of Medical Sciences (Skims) Soura, Srinagar by using allium Cepa test. *Journal of Experimental Biology and Agricultural Sciences*, 8, 48–53. [https://doi.org/10.18006/2020.8\(1\).48.53](https://doi.org/10.18006/2020.8(1).48.53)
- Hu, T., Liu, J., Zheng, G., Li, Y., & Xie, B. (2018). Quantitative assessment of urban wetland dynamics using high spatial resolution satellite imagery between 2000 and 2013. *Scientific Reports*, 8, 1–10. <https://doi.org/10.1038/s41598-018-25823-9>
- ISRO. (2005). NNRMS standards: A national standard for EO images, thematic and cartographic maps, GIS databases and spatial outputs. *ISRO NNRMS Tech Rep No*, 112, 235pp.
- Jeelani, M., & Kaur, H. (2012). Ecological understanding of Anchar Lake, Kashmir. *International journal for environmental rehabilitation and conservation*, 3, 21–32. Weblink: https://essence-journal.com/wp-content/uploads/Archives/Volume_III/Issue_2/Ecological-understanding-of-Anchar-lake-Kashmir.pdf
- Jensen, J. R. (1996). *Introductory digital image processing: A remote sensing perspective* (2nd ed.). Prentice Hall, Inc..
- Joshi, P. K., Rashid, H., & Roy, P. S. (2002). Landscape dynamics in Hokersar wetland, Jammu & Kashmir—an application of geospatial approach. *Journal of the Indian Society of Remote Sensing*, 30, 1–5. <https://doi.org/10.1007/BF02989971>
- Junk, W. J., An, S., Finlayson, C. M., Gopal, B., Kvet, J., Mitchell, S. A., Mitsch, W. J., & Robarts, R. D. (2013). Current state of knowledge regarding the world's wetlands and their future under global climate change: A synthesis. *Aquatic Sciences*, 75, 151–167. <https://doi.org/10.1007/s00027-012-0278-z>
- Khanday, S. A., Romshoo, S. A., Jehangir, A., Sahay, A., & Chauhan, P. (2018). Environmetric and GIS techniques for hydrochemical characterization of the dal Lake, Kashmir Himalaya, India. *Stochastic Environmental Research and Risk Assessment*, 32, 3151–3168. <https://doi.org/10.1007/s00477-018-1581-6>
- Khanday, Z. A., & Khanday, Z. H. (2018). Phytoplankton dynamics in Anchar Lake, Kashmir. *International journal of recent scientific research*, 9, 29210–29213. <https://doi.org/10.24327/ijrsr.2018.0910.2813>
- Krina, A., Xystrakis, F., Karantininis, K., & Koutsias, N. (2020). Monitoring and projecting land use/land cover changes of eleven large deltaic areas in Greece from 1945 onwards. *Remote Sensing*, 12, 1241. <https://doi.org/10.3390/rs12081241>
- Kumar, R. (2016). Wular Lake, Kashmir. In C. Finlayson, G. Milton, R. Prentice, & N. Davidson (Eds.), *The wetland book*. Springer. https://doi.org/10.1007/978-94-007-4001-3_250
- Laurance, S. G. W., Baidar, C., Vincent Florens, F. B., Ramrekha, S., Sevathian, J. C., & Hammond, D. S. (2012). Drivers of wetland disturbance and biodiversity impacts on a tropical oceanic island. *Biological Conservation*, 149, 136–142. <https://doi.org/10.1016/j.biocon.2011.12.015>
- Lea, C., & Curtis, A. C. (2010). Thematic accuracy assessment procedures: National Park Service vegetation inventory, version 2.0. Natural resource report NPS/2010/NRR—2010/204. National Park Service, Fort Collins, Colorado, USA. Weblink: https://www1.usgs.gov/vip/standards/NPSVI_Accuracy_Assessment_Guidelines_ver2.pdf. Accessed 21 Jan 2020.
- Lillseand, T. M., Kiefer, R. W., & Chipman, J. W. (2015). *Remote sensing and image interpretation (7th edition)*. John Wiley and Sons.
- Malik, M., Balkhi, M. H., Abubakr, A., & Bhat, F. (2017). Assessment of trophic state of Nagin Lake based on limnological and bacteriological studies. *Nature environment and pollution technology*, 16, 485–491 Weblink: [http://www.neptjournal.com/upload-images/NL-60-20-\(18\)B-3429com.pdf](http://www.neptjournal.com/upload-images/NL-60-20-(18)B-3429com.pdf)
- Millennium Ecosystem Assessment. (2005). Ecosystems and human well-being: Wetlands and water. World Resources Institute.
- Mir, A. Q., Pandey, G. C., & Sarwar, S. G. (2005). Impact of SKIMS effluent on the water quality of Anchar lake. *Kashmir. Fundamentals of Limnology. SB Nangia for APH Publishing Corporation*, 5, 44–49.
- Mitsch, W. J., & Gosselink, J. G. (2000). The value of wetlands: Importance of scale and landscape setting. *Ecological Economics*, 35, 25–33. [https://doi.org/10.1016/S0921-8009\(00\)00165-8](https://doi.org/10.1016/S0921-8009(00)00165-8)
- Najar, I. A., Khan, A. B., & Hai, A. (2017). Evaluation of seasonal variability in surface water quality of Shallow Valley Lake, Kashmir, India, using multivariate statistical techniques. *Pollution*, 3, 349–362. <https://doi.org/10.7508/pj.2017.03.001>
- Nisar, M. (2016). A geospatial approach to study environmental characterization of a Kashmir wetland (Anchar) catchment with special reference to land use/land cover and changing climate. Ph.D Thesis, Sher-e-Kashmir University of Agricultural Sciences and Technology, Kashmir. Weblink: <http://krishikosh.egranth.ac.in/handle/1/91309>
- Nissa, M., & Bhat, S. U. (2016). An assessment of phytoplankton in Nigeen Lake of Kashmir Himalaya. *Asian Journal of Biological Sciences*, 9, 27–40. <https://doi.org/10.3923/ajbs.2016.27.40>
- OECD (Organization for Economic Cooperation and Development). (1982). *Eutrophication of waters, monitoring, assessment and control, Final report OECD cooperative programme on monitoring of inland waters (eutrophication control)* (154). Environment Directorate. <https://doi.org/10.1002/iroh.19840690206>
- Pandit, A. K. (1988). Threats to Kashmir wetlands and their wildlife resources. *Environmental Conservation*, 15, 266–268. <https://doi.org/10.1017/S0376892900029441>
- Pandit, A. K. (1991). Conservation of wildlife resources in wetland ecosystems of Kashmir, India. *Journal of*

- Environmental Management*, 33, 143–154. [https://doi.org/10.1016/S0301-4797\(05\)80090-8](https://doi.org/10.1016/S0301-4797(05)80090-8)
- Parvez, S., & Bhat, S. U. (2014). Searching for water quality improvement in dal lake, Srinagar, Kashmir. *Journal of Himalayan ecology and sustainable development*, 9, 51–64. Weblink: <http://envircs.uok.edu.in/Files/ab1ac1f1-07e3-42a2-85bc-83717ef39155/Journal/0f7e8ec3-3997-4af6-b6f5-9cd55b18fd3b.pdf>.
- Penatti, N. C., de Almeida, T. I. R., Ferreira, L. G., Arantes, A. E., & Coe, M. T. (2015). Satellite-based hydrological dynamics of the world's largest continuous wetland. *Remote Sensing of Environment*, 170, 1–13. <https://doi.org/10.1016/j.rse.2015.08.031>
- Rashid, I., & Aneaus, S. (2019). High-resolution earth observation data for assessing the impact of land system changes on wetland health in Kashmir Himalaya, India. *Arabian Journal of Geosciences*, 12, 1–13. <https://doi.org/10.1007/s12517-019-4649-9>
- Rashid, I., Bhat, M. A., & Romshoo, S. A. (2017a). Assessing changes in the above ground biomass and carbon stocks of Lidder valley, Kashmir Himalaya, India. *Geocarto International*, 32, 717–734. <https://doi.org/10.1080/10106049.2016.1188164>
- Rashid, I., Farooq, M., Muslim, M., & Romshoo, S. A. (2013). Assessing the impact of anthropogenic activities on Manasbal Lake in Kashmir Himalayas. *International Journal of Environmental Sciences*, 3, 2036–2047. <https://doi.org/10.6088/ijes.2013030600023>
- Rashid, I., Majeed, U., Aneaus, S., & Peltó, M. (2020). Linking the recent glacier retreat and depleting streamflow patterns with land system changes in Kashmir Himalaya, India. *Water*, 12, 1168. <https://doi.org/10.3390/w12041168>
- Rashid, I., & Romshoo, S. A. (2013). Impact of anthropogenic activities on water quality of Lidder River in Kashmir Himalayas. *Environmental Monitoring and Assessment*, 185, 4705–4719. <https://doi.org/10.1007/s10661-012-2898-0>
- Rashid, I., Romshoo, S. A., Amin, M., Khanday, S. A., & Chauhan, P. (2017b). Linking human-biophysical interactions with the trophic status of dal Lake, Kashmir Himalaya, India. *Limnologica*, 62, 84–96. <https://doi.org/10.1016/j.limno.2016.11.008>
- Rather, I. A., & Dar, A. Q. (2020). Spatio-temporal variation in physio-chemical parameters over a 20-year period, potential future strategies for management: A case study of dal Lake, NW Himalaya India. *Environmental Technology & Innovation*, 20, 101102. <https://doi.org/10.1016/j.eti.2020.101102>
- Rather, M. I., Rashid, I., Shahi, N., Murtaza, K. O., Hassan, K., Yousuf, A. R., Romshoo, S. A., & Shah, I. Y. (2016). Massive land system changes impact water quality of the Jhelum River in Kashmir Himalaya. *Environmental Monitoring and Assessment*, 188, 1–20. <https://doi.org/10.1007/s10661-016-5190-x>
- Reis, V., Hermoso, V., Hamilton, S. K., Ward, D., Fluet-Chouinard, E., Lehner, B., & Linke, S. (2017). A global assessment of inland wetland conservation status. *Bioscience*, 67, 523–533. <https://doi.org/10.1093/biosci/bix045>
- Reiss, K. C., Hernandez, E., & Brown, M. T. (2014). Application of the landscape development intensity (LDI) index in wetland mitigation banking. *Ecological Modelling*, 271, 83–89. <https://doi.org/10.1016/j.ecolmodel.2013.04.017>
- Romshoo, S. A., Ali, N., & Rashid, I. (2011). Geoinformatics for characterizing and understanding the spatio-temporal dynamics (1969–2008) of Hokarser wetland in Kashmir Himalayas. *International Journal of Physical Science*, 6, 1026–1038. <https://doi.org/10.5897/IJPS10.378>
- Romshoo, S. A., Altaf, S., Rashid, I., & Dar, R. A. (2017). Climatic, geomorphic and anthropogenic drivers of the 2014 extreme flooding in the Jhelum basin of Kashmir, India. *Geomatics, Natural Hazards and Risk*, 9, 224–248. <https://doi.org/10.1080/19475705.2017.1417332>
- Romshoo, S. A., Dar, R. A., Rashid, I., Marazi, A., Zaz, S., & Ali, N. (2015). Implications of shrinking cryosphere under changing climate on the streamflows in the Lidder catchment in the upper Indus Basin, India. *Arctic, Antarctic, and Alpine Research*, 47, 627–644. <https://doi.org/10.1657/AAAR0014-088>
- Romshoo, S. A., & Muslim, M. (2011). Geospatial modelling for assessing the nutrient load of a Himalayan lake. *Environmental Earth Sciences*, 64, 1269–1282. <https://doi.org/10.1007/s12665-011-0944-9>
- Romshoo, S. A., & Rashid, I. (2014). Assessing the impacts of changing land cover and climate on Hokarser wetland in Indian Himalayas. *Arabian Journal of Geosciences*, 7, 143–160. <https://doi.org/10.1007/s12517-012-0761-9>
- Russi, D., ten Brink, P., Farmer, A., Badura, T., Coates, D., Förster, J., Kumar, R., & Davidson, N. (2013). The economics of ecosystems and biodiversity for water and wetlands. In *IEEP, London and Brussels*. Gland.
- Saluja, R., & Garg, J. K. (2017). Trophic state assessment of Bhindawas Lake, Haryana, India. *Environmental Monitoring and Assessment*, 189, 1–15. <https://doi.org/10.1007/s10661-016-5735-z>
- Setianto, A., & Triandini, T. (2013). Comparison of kriging and inverse distance weighted (Idw) interpolation methods in lineament extraction and analysis. *Journal of Applied Geology*, 5, 21–29. <https://doi.org/10.22146/jag.7204>
- Shah, J. A., Pandit, A. K., & Shah, G. M. (2015). Dynamics of key plant nutrients (N & P) in hokersar, a typical wetland of Kashmir Himalaya, India. *Journal of Environmental Engineering & Ecological Science*, 4, 1–7. <https://doi.org/10.7243/2050-1323-4-1>
- Shah, J. A., Pandit, A. K., & Shah, G. M. (2017). Dynamics of physico-chemical limnology of a shallow wetland in Kashmir Himalaya (India). *Sustain. Water Resources Management*, 3, 465–477. <https://doi.org/10.1007/s40899-017-0115-6>
- Shah, M. A., Shah, A. B., & Reshi, Z. A. (2020). Aquatic ecosystems of Jammu and Kashmir state. In G. H. Dar & A. A. Khuroo (Eds.), *Biodiversity of the Himalaya: Jammu and Kashmir state*. Springer. https://doi.org/10.1007/978-981-32-9174-4_9
- Showqi, I., Lone, F. A., Mehmood, M. A., Naikoo, M., & Kirmani, N. A. (2018a). Assessment of some macro nutrients to determine the nutritional status of Anchar lake of Kashmir Himalaya. *International journal of Theoretical & Applied Sciences, special issue on environmental contaminants and management*, 10, 46–50. Weblink: https://www.researchtrend.net/ijtas/pdf/9_Irfana_Showqi_Assessment.pdf. Accessed 21 Jan 2020

- Showqi, I., Lone, F. A., & Naikoo, M. (2018b). Preliminary assessment of heavy metals in water, sediment and macrophyte (Lemna minor) collected from Anchar Lake, Kashmir, India. *Applied Water Science*, 8, 80. <https://doi.org/10.1007/s13201-018-0720-z>
- Showqi, I., Rashid, I., & Romshoo, S. A. (2014). Land use land cover dynamics as a function of changing demography and hydrology. *GeoJournal*, 79, 297–307. <https://doi.org/10.1007/s10708-013-9494-x>
- Siraj, S., Yousuf, A. R., Bhat, F. A., & Parveen, M. (2010). The ecology of macrozoobenthos in Shallabugh wetland of Kashmir Himalaya, India. *Journal of ecology and the natural environment*, 2, 84–91 Weblink: http://www.academicjournals.org/app/webroot/article/article1379596092_Siraj%20et%20al.pdf. Accessed 21 Jan 2020
- Sushil, M., Reshi, J. M., & Krishna, M. (2014). To evaluate the water quality status and responsible factors for variation in Anchar Lake, Kashmir. *IOSR journal of environmental science, toxicology and food technology (IOSR-JESTFT)*, 8, 55–62 Weblink: <https://pdfs.semanticscholar.org/d55c/6fd8eeaa0ff03c63842dde67ca18e33724ed.pdf>
- Tahseen, Abubakr, A., & Balkhi, M. H. (2018). Trophic status assessment of Anchar Lake, Kashmir. *Journal of Pharmacognosy and Phytochemistry*, 7, 1154–1156 Weblink: <http://www.phytojournal.com/archives/2018/vol7issue4/PartS/7-4-36-183.pdf>
- Turner, R. K., van der Bergh, J. C. J. M., Soderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E., & van Lerland, E. C. (2000). Ecological economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics*, 35, 7–23. [https://doi.org/10.1016/S0921-8009\(00\)00164-6](https://doi.org/10.1016/S0921-8009(00)00164-6)
- Torbick, N. M., Qi, J., Roloff, G. J., & Stevenson, R. J. (2006). Investigating impacts of land-use land cover change on wetlands in the Muskegon River watershed, Michigan, USA. *Wetlands*, 26, 1103–1113. [https://doi.org/10.1672/0277-5212\(2006\)26\[1103:IIOLLC\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2006)26[1103:IIOLLC]2.0.CO;2)
- Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy, L., & C., & Davies, P. M. (2010). Global threats to human water security and river biodiversity. *Nature*, 467, 555–561. <https://doi.org/10.1038/nature09440>
- Widney, S., Kanabrocki Klein, A., Ehman, J., Hackney, C., & Craft, C. (2018). The value of wetlands for water quality improvement: An example from the St. Johns River watershed, Florida. *Wetlands Ecology and Management*, 26, 265–276. <https://doi.org/10.1007/s11273-017-9569-4>
- Wetzel, R.G., 2001. Limnology: Lake and river ecosystems. 3rd edition. California, USA; academic press; An imprint of Elsevier.
- Woodward, R. T., & Wui, Y. S. (2001). The economic value of wetland services: A meta-analysis. *Ecological economic*, 37, 257–270. [https://doi.org/10.1016/S0921-8009\(00\)00276-7](https://doi.org/10.1016/S0921-8009(00)00276-7)
- Xu, F. L., Tao, S., Dawson, R. W., & Li, B. G. (2001). A GIS-based method of lake eutrophication assessment. *Ecological Modelling*, 144, 231–244. [https://doi.org/10.1016/S0304-3800\(01\)00374-X](https://doi.org/10.1016/S0304-3800(01)00374-X)
- Yu, L., Li, M., Wang, S. H., & Zhao, Y. W. (2010). Wetland landscape change in Daliaohe River basin and the driving factors analysis. *Procedia Environmental Sciences*, 2, 1255–1264. <https://doi.org/10.1016/j.proenv.2010.10.136>
- Zedler, J. B., & Kercher, S. (2005). Wetland resources: Status, trends, ecosystem services and restorability. *Annu Rev of Environ Res.*, 30, 39–74. <https://doi.org/10.1146/annurev.energy.30.050504.144248>
- Zhang, W. W., Yao, L., Li, H., Sun, D. F., & Zhou, L. D. (2011). Research on land use change in Beijing Hanshiqiao wetland nature reserve using remote sensing and GIS. *Procedia Environmental Sciences*, 10, 583–588. <https://doi.org/10.1016/j.proenv.2011.09.094>
- Zutshi, D. P., Subla, B. A., Khan, M. A., & Wanganeo, A. (1980). Comparative limnology of nine lakes of Jammu and Kashmir Himalayas. *Hydrobiologia*, 72, 101–112. <https://doi.org/10.1007/BF00016238>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.